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DIRECTIONS

FOR

MAKING THE BEST COMPOSITION

FOR THE

METALS OF REFLECTING TELESCOPES.

TOGETHER WITH

A Deſcription of the Proceſs for grinding, poliſhing, and giving the great Speculum the true parabolic Curve.

By Mr. JOHN MUDGE.

Read at the ROYAL SOCIETY, Feb. 27. March 6. and 13. 1777.

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DIRECTIONS, &c.

AS the method of caſting, grinding, and poliſhing the ſpecula of reflecting teleſcopes, by Meſſ. MOLYNEUX and HADLEY, which is publiſhed in Dr. SMITH's Optics, is what the workmen have generally followed, and is conſequently well known to them; I ſhall in the following account avoid a repetition of the general directions there given, and only remark upon ſuch parts of that proceſs which I think are eſſentially defective, and ſupply them by a method of my own, which, from long and repeated trials, I have found completely to anſwer the purpoſe. After, therefore, referring to the above account for the manner of making the gages, patterns, the method of caſting, as well as a great many other particulars, I will begin with

The beſt compoſition for the ſpecula of reflecting teleſcopes.

The perfection of the metal of which the ſpeculum ſhould be made conſiſts in its hardneſs, whiteneſs, and compactneſs; for upon theſe properties the reflective powers and durability of the ſpeculum depend. And firſt of the hardneſs and whiteneſs of the metal. There are various compoſitions recommended in SMITH's Optics, all which have however their ſeveral defects. Three parts copper and one part and one-fourth of tin will make, he ſays, a very hard white metal; but it is liable to be porous. This, however, is an imperfection which I ſhall preſently ſhew the method of preventing; but the permanent fault of it, and which I have myſelf experienced, is, that it is not hard enough. The ſpeculum of a reflecting teleſcope ought to have the utmoſt poſſible hardneſs, compatible with its being operated upon by the tool.

It is to be obſerved, that ever ſo ſmall a quantity of tin added to melted copper deſtroys its perfect malleability, and at the ſame time produces a metal whiter and harder than copper. As the quantity of tin is increaſed, ſuppoſe to a fifth or fourth part, the metal becomes whiter, ſtill harder, and conſequently more friable. If the quantity of tin be further increaſed to a third of the whole compoſition, it will then have its utmoſt whiteneſs; but will be rendered at the ſame time ſo exceedingly hard and brittle, that the fineſt waſhed emery upon lead or braſs will not cut it without breaking up its ſurface; and the common blue ſtones uſed in grinding the ſpeculum, will not touch it. Mr. JACKSON (ſome time ſince dead) a mathematical-inſtrument-maker, and a moſt excellent workman, told me, that the tin was increaſed to the above proportion in his metals; but that they were ſo exceedingly hard, that it coſt him an infinite deal of pains, and a journey of two hundred miles, to find out a ſtone of ſufficient hardneſs to cut it, and whoſe texture at the ſame time was fine enough not to injure its ſurface. I have ſeen ſeveral of his finiſhed metals; they were indeed perfectly hard and white; but the kind of ſtone with which he ground them he kept a ſecret.

After many experiments with various proportions of tin and copper, by gradually increaſing the former, I at laſt found that fourteen ounces and an half of grain-tin to two pounds of good Swediſh copper, made a beautiful white and very hard metal; ſo hard indeed, that the ſtones would but barely cut it, and waſhed emery on braſs or tin but juſt grind the ſurface without breaking it up; whereas the proportion of tin being increaſed by the addition of only another half ounce, the former inconvenience immediately took place. This therefore is the *maximum* in point of hardneſs.

Thus much of the two firſt conſiderations, the hardneſs and whiteneſs of the metal; the next, and indeed the moſt eſſential, property is its compactneſs, or its being without pores.

This compoſition (though complete in the former reſpects) was, as well as Dr. SMITH'S, ſubject every now and then to be porous; ſometimes, indeed, I ſucceeded in caſting a ſingle metal, or perhaps two or three, without this imperfection; at other times, and moſt frequently indeed, they were attended with this defect, without my being at all able to form a probable conjecture at the cauſe of my ſucceſs or diſappointment. The pores were ſo very ſmall that they were not diſcoverable when the metal had received a good face and figure upon the hones, nor till the laſt and higheſt poliſh had been given; and then it frequently appeared as if duſted over with millions of microſcopic pores, which were exceedingly prejudicial in two reſpects; for firſt, they became in time a lodgment for a moiſture which tarniſhed the ſurface; and ſecondly, on poliſhing the ſpeculum, the putty neceſſarily rounded off the edges of the pores, ſo as to ſpoil a great part of the metal, by the loſs of as much light and ſharpneſs in the image as there were defective points of reflection in the metal.

Beſides the trouble of a great number of experiments, in order to get rid of this miſchief, and to aſcertain the cauſe to which it was owing, there was this additional inconvenience attending it, *viz.* that the fault was not diſcovered, as was obſerved before, till a great deal of trouble had been taken in grinding and even poliſhing the metal, the whole of which was rendered uſeleſs by the mortifying diſcovery of this defect.

I was extricated at laſt from this difficulty, and in ſome meaſure by accident. Having one day made a great number of experiments, and having melted down all the good copper I had or could procure; though puzzled and fatigued, yet not caring to give it up, I recollected that I had ſome metal which was reſerved out of curioſity, and was a part of one the bells of St. Andrew's which had been re-caſt. Expecting, however, very little from this groſs and uncertain compoſition, I was nevertheleſs determined to ſee what could be made of it by enriching the compoſition with a little freſh tin. Accordingly caſting a metal with it, it turned out perfectly free from pores, and in every reſpect as fine a metal as ever I ſaw.

I could not at firſt conceive to what this ſucceſs was owing; but at laſt I hit upon the real cauſe of that defect, which had given me ſo much embarraſſment and trouble during a courſe of near a hundred experiments, and in conſequence thereof fell upon a method which ever after prevented it.

I had hitherto always melted the copper firſt, and when it was ſufficiently fuſed, I uſed to add the proportional quantity of tin; and as ſoon as the two were mixed, and the ſcoria taken off, the metal was poured into the moulds. I began to conſider that putty was calcined tin, and ſtrongly ſuſpected, that the exceſſive heat which the copper neceſſarily undergoes before fuſion, was ſufficient to reduce part of the tin to this ſtate of calcination, which therefore might fly off from the compoſition in the form of putty, at the time the metal was poured into the flaſks.

Upon this idea, after I had furniſhed myſelf with ſome more Swediſh copper and grain-tin (both which I had always before uſed) I melted the copper, and having added the tin as uſual to it, caſt the whole into an ingot: this was, as I expected, porous. I then melted it again, and as in this mixed ſtate it did not acquire half the heat which was before neceſſary to melt the copper alone, ſo it was not ſufficient to calcine the tin; the ſpeculum was then perfectly cloſe, and free from this fault; nor did I ever after, in a ſingle inſtance, meet with the above mentioned imperfection.

All that is neceſſary, therefore, to be done to procure a metal which ſhall be white, as hard as it can be wrought, and perfectly compact, is to melt two pounds of Swediſh copper, and when ſo melted, to add fourteen ounces and a half of grain-tin to it; then, having taken off the ſcoria, to caſt it into an ingot. This metal muſt be a ſecond time melted to caſt the ſpeculum; but as it will fuſe in this compound ſtate with a ſmall heat, and therefore will not calcine the tin into putty, it ſhould be poured off as ſoon as it is melted, giving it no more heat than is abſolutely neceſſary. It is to be obſerved, however, that the ſame metal, by frequent melting, loſes ſomething of its hardneſs and whiteneſs: when this is the caſe, it becomes neceſſary to enrich the metal by the addition of a little tin, perhaps in the proportion of half an ounce to a pound. And indeed when the metal is firſt made, if inſtead of adding the fourteen ounces and a half of tin to the two pounds of melted copper, about one ounce of the tin were to be reſerved and added to it in the ſucceeding melting, before it is caſt off into the moulds, the compoſition would be the more beautiful, and the grain of it much finer: this I know by experience to be the caſe.

The beſt method for giving the melted metal a good ſurface is this: the moment before it is poured off, throw into the crucible a ſpoonful of charcoal-duſt; immediately after which the metal muſt be ſtirred with a wooden ſpatula, and poured into the moulds.

I wiſh I may not be conſidered as tedious in the above detail; but as this buſineſs cauſed me a great deal of trouble, I was willing to give ſome account of the means by which I was freed from this difficulty ever after. Perhaps, indeed, the whole of this proceſs may be unneceſſary, as many years ſince, I communicated this compoſition, and I believe at the ſame time the method of preventing the pores, to the late Mr. PETER COLLISON, a member of the Royal Society; and likewiſe two or three years ſince, at the deſire of my brother, to Mr. MICHELL. Although it be poſſible, therefore, that this method is generally known, yet, as I have frequently of late ſeen ſpecula with this defect, and obſerved metals of ſome of Mr. SHORT's teleſcopes which are not quite ſo perfect as could be wiſhed (though they are all exquiſitely figured) I was willing by this publication wholly to remove any future embarraſſment of this ſort, and to furniſh workmen with an excellent compoſition for their metals. And would the Royal Society be pleaſed to honour the proceſs with a place in their records, I know of no other method ſo proper to give this, as well as the following information, a general notoriety.

The metal being caſt, there will be no occaſion for the complicated apparatus directed by Dr. SMITH, for grinding and poliſhing it. Four tools are all that are neceſſary, *viz.* the rough grinder to work off the rough face of the metal; a braſs convex grinder, on which the metal is to receive its ſpherical figure; a bed of hones which is to perfect that figure, and to give the metal a fine ſmooth face; and a concave tool or bruiſer, with which both the braſs grinder, and the hones are to be formed. A poliſher may be conſidered as an additional tool; but as the braſs grinder is uſed for this purpoſe, and its pitchy ſurface is expeditiouſly, and without difficulty formed by the bruiſer, the apparatus is therefore not enlarged.

Of rough grinding the ſpeculum.

The tool by which the rough ſurface of the metal is rendered ſmooth and fit for the hones, is beſt made of lead, ſtiffened with about a fifth or ſixth part of tin. This tool ſhould be at leaſt a third more in diameter than the metal which is to be ground; and for one of any ſize, not leſs than an inch thick. It may be cemented upon a block of wood, in order to raiſe it higher from the bench.

This leaden tool being caſt, it muſt be fixed in the lathe, and turned as true as it is poſſible, by the gage, to the figure of the intended ſpeculum, making a hole or pit in the middle, as a lodgment for the emery, of about an inch diameter for a metal of four inches: when this is done, deep grooves muſt be cut acroſs its ſurface with a graver, in the manner repreſented in fig. 1. Theſe grooves will ſerve to lodge the emery, and by their means the tool will cut a great deal faſter. There is no occaſion to fear any alteration in the convexity of this tool by working the metal upon it, for the emery will bed itſelf in the lead, and ſo far arm the ſurface of it, that it will preſerve its figure and cut the metal very faſt. Any kind of low handle, fixed on the back of the metal with ſoft cement, will be ſufficient; but it ſhould cover two-thirds of its back to prevent its bending. This way of working will cut the metal faſter, and with more truth, than the method deſcribed by Dr. SMITH; for ſhould the ſurface and rough parts be attempted to be ground off by a common grind-ſtone by hand, though you did it as near the gage as poſſible, yet the metal would be ſo much out of truth when applied to the ſucceeding tool, that no time would be ſaved by it. I uſed to employ a common labourer for this purpoſe, who ſoon acquired ſuch a dexterity at working upon this tool, that in two hours time he would give a metal of four inches diameter ſo good a face and figure as even to fit it for the hones. When all the ſand-holes and irregularities on the face of the metal are ground off, and the whole ſurface is ſmooth and regularly figured, the ſpeculum is then ready for the braſs grinder, and muſt be laid aſide for the preſent.

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The manner of forming the braſs-grinding tool.

The following is the method I have always purſued. Procure a round ſtout piece of Hamburgh braſs, at moſt a ſixth part larger than the metal to be poliſhed; and let it be well hammered into a degree of convexity (by the aſſiſtance of the gage) ſuitable to the intended ſpeculum. Having done this, ſcrape and clean the concave ſide ſo thoroughly that it may be well tinned all over; then caſt upon it, after it has been preſſed a proper depth into the ſand, the former compoſition of tin and lead, in ſuch quantity, that it may (for a ſpeculum of four inches diameter) be at leaſt an inch and an half thick, and with a baſe conſiderably broader than the top, in order that it may ſtand firmly upon the bench in the manner hereafter to be deſcribed. This being done, it muſt be fixed and turned in the lathe with great care, and of ſuch a convexity as exactly to ſuit the concave gage, which we ſuppoſe already made. It will be neceſſary to be more careful in forming this than the former tool, and eſpecially that no rings be left from the turning;

nor will the ſucceeding hone tool require ſo much exactneſs, as any defects in turning, will, by a method hereafter mentioned, be eaſily remedied; but any inequality or want of truth in the braſs tool will occaſion a great deal of trouble before it can be ground out by the emery. This tool muſt have a hole (ſomewhat leſs than that in the metal to be worked upon it) in the middle, quite through to the bottom. When this tool is finiſhed off in the lathe, its diameter ſhould be one-eighth wider than the metal.

How to form the bed of hones, or the third tool.

Having choſen the kind of hones, and the beſt too, of the ſort recommended in SMITH's Optics; they ſhould be cemented in ſmall pieces (in a kind of pavement agreeably to his directions) upon a thick round piece of marble, or metal made of lead and tin like the former compoſition (which is what I have always uſed) in ſuch a manner, that the lines between the ſtones may run ſtraight from one ſide to the other; ſo that, placing the teeth of a fine ſaw in each of theſe diviſions, they may be cleared from one end to the other of the cement which riſes between the ſtones. This bed of hones ſhould be at leaſt a fourth part larger than the metal which is to be ground upon it. The ſurface of the metal upon which the hone pavement is to be cemented may or may not, as you pleaſe, be turned of a convexity ſuitable to the gage, though I have never taken that trouble. As ſoon as the hones are cemented down, and the joints cleared by the ſaw, this tool muſt be fixed in the lathe, and turned as exactly true to the gage as poſſible; which done, it muſt be laid aſide for the preſent. The next tool to be made is the bruiſer.

The manner of forming the bruiſer, the fourth and laſt tool.

This tool ſhould be likewiſe made of thick ſtout braſs like the former, perfectly ſound, about a quarter of an inch thick, and hammered as near to the gage as poſſible. It ſhould be then ſcraped, cleaned, and tinned on the convex ſide, as the former tool was on the concave, and the ſame thickneſs of lead and tin caſt upon it. The general ſhape of this ſhould differ from the former; for as that increaſed in diameter at the bottom for the ſake of ſtanding firmly, ſo this ſhould be only as broad at bottom as at top, as it is to be uſed occaſionally in both thoſe poſitions. When this tool is fixed in the lathe, and turned off concave to the convex gage with great truth likewiſe, its diameter ought to be the middle ſize between the hones and the poliſher.

Having with the lathe roughly formed the convex braſs grinder, the bed of hones, and the concave bruiſers, the convex and concave braſs tools and the metal muſt be wrought alternately and reciprocally upon each other with fine emery and water, ſo as to keep them as nearly to the ſame figure as poſſible, in order to which ſome waſhed emery muſt be procured. This is beſt done by putting it into a phial, which muſt be half filled with water and well ſhaken up, ſo that, as it ſubſides, the coarſeſt may fall to the bottom firſt, and the fineſt remain at the top: and whenever freſh emery is laid on the tools, the beſt method (which we ſhould alſo obſerve with the putty in poliſhing) will be, to ſhake gently the bottle, and pour out a ſmall quantity of the turbid mixture.

Of grinding the ſpeculum, the braſs tool, and the bruiſer, together.

All the tools being ready, upon a firm poſt in the middle of a room, you are to begin to grind the braſs convex tool with the bruiſer upon it, working the latter croſsways, with ſtrokes ſometimes acroſs its diameter, at others a little to the right and left, and always ſo ſhort that the bruiſers may not paſs above half an inch within the ſurface of the braſs tool either way, ſhifting the bruiſer round its axis every half dozen ſtrokes or thereabout. You muſt likewiſe, every now and then, ſhift your own poſition, by walking round, and working at different ſides of the braſs tool; at times the ſtrokes ſhould be carried round and round, but not much over the tool: in ſhort, they muſt be directed in ſuch a way, and the whole grinding conducted in ſuch a manner and with ſuch equability, that every part of both tools may wear equally. This habit of grinding, as well as the future one of poliſhing, will be ſoon acquired. When you have wrought in this manner about a quarter of an hour with the bruiſer upon the tool, it will be then neceſſary to change them, and, placing the bruiſer upon its bottom, to work the convex tool upon that in the ſame manner.

When by working in this equable manner, alternately with the bruiſer and tool, and occaſionally adding freſh emery, you have nearly got out all the veſtiges of the turning tool, and brought them both nearly to a figure, it will be then time to give the ſame form to the metal. This muſt be done by now and then grinding it upon the braſs tool with the ſame kind of emery, taking care however, by working the two former tools frequently together, to keep all three exactly in the ſame curve.

The beſt kind of handle for the metal is made of lead, a little more than double its thickneſs, and ſomewhat leſs in diameter, of about three pounds weight, with a hole in the middle (for reaſons to be ſhewn hereafter) a little larger than that in the metal: this handle ſhould be cemented on with pitch. The upper edge of this weight muſt be rounded off, that the fingers may not be hurt; and a groove, about the bigneſs of the little finger, be turned round juſt below it, for the more conveniently holding and taking the metal off the tools.

The manner of figuring the metal upon the hones.

When the bruiſer, braſs tool, and metal, are all brought to the ſame figure, and have all a true good ſurface, the next part of the proceſs is to give a correct ſpherical figure and a fine face to the metal, upon the hones. It will be neceſſary to premiſe, however, that the hones ſhould be placed in a veſſel of water, with which they ſhould be quite covered for at leaſt an hour before they are uſed, otherwiſe they will be perpetually altering their figure when the metal comes to be ground upon them. The ſame precaution is alſo neceſſary, if you are called off from the work while you are grinding the metal, for if they be ſuffered to grow dry, the ſame inconvenience will ariſe.

In order to give a proper figure to the hones, and exactly ſuitable to that of the braſs tool, bruiſer, and metal, when the hones are fixed down to the block, ſome common flour emery (unwaſhed) with a good deal of water muſt be put upon them, and the bruiſer being placed upon the hones and rubbed thereon with a few ſtrokes and a light hand, the inequalities of the ſtone will be quickly worn off; but as a great deal of mud will be ſuddenly generated, it muſt be waſhed off every quarter of a minute with a great deal of water. By a repetition of this, two or three times, the hones (being of a very ſoft and friable ſubſtance) will be cut down to the figure, without wearing or altering the bruiſer at all. Though this buſineſs may be quickly done, and can be continued but for a few ſtrokes at a time, I need not ſay that it is neceſſary that thoſe ſtrokes be carried in the ſame direction, and with the ſame care, which was obſerved in grinding the former tools together.

As ſoon as the hones have received the general figure of the bruiſer, and all the turning ſtrokes are worn out from them, the emery muſt be carefully waſhed off; in order to which, it will be neceſſary to clear it from the joints with a bruſh under a ſtream of water. The bruiſer and metal muſt be likewiſe cleared in the ſame manner, and with equal care, from any lurking particles of emery.

The hones being fixed down to the block, you now begin to work the bruiſer upon them with very cautious, regular, ſhort ſtrokes, forward and backward, to the right and left, turning the axis of the bruiſer in the hand while you move round the hones, by ſhifting your poſition, and walking round the block. Indeed the whole now depends upon a knack in working, which ſhould be conducted nearly in the following manner. Having placed the bruiſer on the centre of the hones, ſlide it in an equable manner forward and backward, with a ſtroke or two directly acroſs the diameter, a little on one ſide, and ſo on the other; then ſhifting your poſition an eighth part round the block, and having turned the bruiſer in your hand about as much, give it a ſtroke or two round and round, but not far over the edges of the hones, and then repeat the croſs ſtrokes as before: thoſe round ſtrokes (which ought not to be above two or three at moſt) are given every time you ſhift your own poſition and that of the metals, previous to the croſs ones, in order to take out any ſtripes either in the hones or bruiſer, which may be ſuppoſed to be occaſioned, by the ſtraight croſs ſtrokes. During the time of working, no mud muſt be ſuffered to collect upon the hones, ſo as to deſtroy the perfect contact between the two tools; and therefore they muſt every now and then be waſhed clean by throwing ſome water upon them. When by working in this manner all the emery ſtrokes are ground off from the bruiſer, and it has acquired a good figure and clean ſurface, you may then begin with the metal upon the hones, in the ſame cautious manner, waſhing off the mud as faſt as it collects, though that will be much leſs now than when the bruiſer was ground upon them. Every now and then, however, the bruiſer muſt be rubbed gently and lightly upon the hones, which will as it were, by ſharpening them and preventing too great ſmoothneſs, occaſion them to cut the metal much faſter.

When, after having ſome time cautiouſly wrought in the manner before deſcribed, the hone-pavement has uniformly taken out all the emery ſtrokes, and given a fine face and true figure to the metal, which will be pretty well known by the great equality there is in the feel while you are working, and by which an experienced workman will form a pretty certain judgment; having proceeded thus far, I ſay, you may then try your metal, and judge of its figure by this more certain manner.

Waſh the hone pavement quite clean; then put the metal upon the center of it, and give two or three light ſtrokes round and round only, not carrying, however, the edges of the metal much over the hones; this will take out the order of ſtraight ſtrokes: then having again waſhed the hones, and placed the ſpeculum upon their center, with gentle preſſure, ſlide it towards you till its edge be brought a little over that of the hones, then carry it quite acroſs the diameter as far the other ſide, and having given the metal a light ſtroke or two in this direction, take it off the tool. The metal being wiped quite dry, place it upon a table at a little diſtance from a window; ſtand yourſelf as near the window, at ſome diſtance from the metal, and looking obliquely on its ſurface, turn it round its axis, and you will ſee at every half turn the grain given by the laſt croſs ſtrokes flaſh upon your eye at once over the whole face of the metal. This is as certain a proof of a true ſpherical figure as the operoſe and difficult method deſcribed in Dr. SMITH's Optics; for as there is nothing ſoft or elaſtic, either in the metal or in the hones, this glare is a certain proof of a perfect contact in every part of the two ſurfaces; which there could not be if the ſpheres were not both perfect and preciſely the ſame.

Indeed there is one accidental circumſtance which neceſſarily affords its aid in this and every buſineſs of the like ſort; and that is, that a concave and convex ſurface ground together, though ever ſo irregular at firſt, will (if the working be uniform and proper, conſiſting, eſpecially at laſt, of croſs ſtrokes in every poſſible direction acroſs the diameter) be formed into portions of true and equal ſpheres; had it not been for this lucky neceſſity, it would have been impoſſible to have produced that correctneſs which is eſſential in the ſpeculum of a good reflecting teleſcope by any mechanic contrivance whatever. For when it is conſidered, that the errors in reflection are four times as great as in refraction, and that the leaſt defect in figure is magnified by the powers of the inſtrument, any thing ſhort of perfection in the figure of the ſpeculum would be evidently perceived by a want of diſtinctneſs in the performance.

I muſt not, however, quit this article without obſerving, that I all along ſuppoſe, both in forming the tools and at laſt figuring the metal (and indeed the ſame muſt be obſerved in the future proceſs of poliſhing) that no kind of preſſure is uſed that may endanger the bending or irregularly grinding them; they ſhould therefore be held with a light hand, and looſely between the fingers, and the motion given ſhould be in a horizontal direction, with no more preſſure than their own dead weight.

Having now finiſhed the metal on the hones, and rendered it both in point of figure and ſurface fit for the laſt and moſt eſſential proceſs, *viz.* that of poliſhing, I will deſcribe it in the beſt manner I can; though many little circumſtances which will be unavoidably omitted (and which at the ſame time are frequently eſſential to the ſucceſs of a mechanic proceſs) can only be ſupplied by actual experience.

The poliſhing the ſpeculum is the moſt difficult and eſſential part of the whole proceſs; for every experienced workman knows, to his vexation, that the moſt trifling error here will be ſufficient to ſpoil the figure of his metal, and render all his preceding caution uſeleſs. I have, however, diſcovered a method which I ſhall explain, not only of giving the metal a parabolic figure, but alſo of recovering it when it happens to be injured; both to be effected in the act of poliſhing, and the former as certainly as the ſpherical figure is given upon the hones. Indeed, if we conſider rightly, poliſhing will be perceived to be but a kind of grinding with a finer order of ſtrokes, and with a powder infinitely finer than was before uſed in what is commonly called the grinding. But before I deſcribe this method, which was the reſult of many years experience, I will take the liberty of making ſome few ſtrictures on that of Meſſ. HADLEY and MOLYNEUX, which is followed by the generality of workmen.

Firſt, then, the tool itſelf uſed by them for poliſhing the metal, is formed with infinite difficulty. The firſt deſcribed poliſher is directed to be made by covering the tool with ſarcenet, which is to be ſaturated with a ſolution of pitch in ſpirit of wine, by ſucceſſive applications of it with a bruſh, till it is covered, and by the evaporation of the ſpirit of wine filled with this extract of pitch; the ſurface is then to be worked down and finiſhed with the bruiſer. This is all very eaſy in imagination; but whoever has uſed this method (which I have myſelf unſucceſsfully ſeveral times) muſt have found it attended with infinite labour, and at laſt the buſineſs done in a very unſatisfactory manner; for the pitch by this proceſs will be deprived of an eſſential part of its compoſition. The ſpirit of wine diſſolves none but the reſinous parts of its ſubſtance, which is hard and untractable; and if you uſe ſoap or ſpirit of wine to ſoften or diſſolve it, it will equally affect the whole ſurface, the lower as well as higher parts of it. And ſuppoſe that with infinite labour with the bruiſer, it is at laſt reduced to a fine uniform ſurface, it is nevertheleſs too hard ever to give a good poliſh with that luſtre which is always ſeen in Mr. SHORT's, and indeed all other good metals. Nor will it give a good ſpherical figure; for a perfect ſphere is formed, as I obſerved before, by that intimate accommodation ariſing from the wear and yielding of both tool and metal; whereas in this method, there is ſuch a ſtubbornneſs in the poliſher, that the figure of the metal, good or bad, muſt depend upon the truth of the former, which is very ſeldom perfect.

If the poliſher be made in the ſecond manner propoſed, by ſtraining the pitch through an outer covering, which is afterwards to be ſtripped off, the ſuperficies of pitch and ſarcenet is ſo very thin, that the putty, working into them, forms a ſurface hard and untractable, ſo that it is impoſſible to give the ſpeculum a fine poliſh. Accordingly all thoſe metals which are wrought that way have an order of ſcratches inſtead of poliſh, diſcovering itſelf by a greyiſh viſible ſurface. Beſides, ſuppoſing this tool perfectly finiſhed, and anſwering its purpoſe ever ſo well, it is impoſſible it can produce in the ſpeculum any other than a ſpherical figure; and indeed nothing elſe is expected from this method, as very evidently appears by the experiment recommended to aſcertain the truth of the figure. You are directed to place a ſmall luminous object in the center of the ſphere of which the metal is a ſegment, and then having adjuſted an eye-glaſs at the diſtance of its own focal length from the object, and ſo ſituated that the image of the object formed by the ſpeculum may be viſible to the eye, you are to judge of the perfect figure of the metal by the ſharpneſs and diſtinctneſs with which the image appears. From hence it is very evident, that as the object and image are both diſtant from the metal by exactly its radius, nothing but a true ſpherical figure of the ſpeculum can produce a ſharp diſtinct image; and that the image could not be diſtinct if the figure of the ſpeculum were parabolic. Conſequently, if the ſame ſpeculum uſed in a teleſcope were to receive parallel rays, there would neceſſarily be a conſiderable aberration produced, and a conſequent imperfection in the image. Accordingly, there never was a good teleſcope made in this manner; for if the number of degrees, or the portion of the ſphere of which the great metal is a part, were as conſiderable as it ought to be, or as great as Mr. SHORT allowed in his metal, the inſtrument would bear but a very low charge, unleſs a great part of the circumference of the metal were cut off by an aperture, and the ill effects of the aberration by that means in ſome meaſure prevented.

If ever a finiſhed metal turned out without this defect, and has been found perfectly ſharp and diſtinct, it muſt have been owing to an accidental parabolic tendency, no ways the natural reſult of the proceſs, and therefore quite unexpected, and moſt probably unknown, to the workman.

Without enlarging, therefore, on the difficulty of the above proceſs, and the impoſſibility of giving the ſpeculum the correctneſs and the kind of figure eſſentially neceſſary to a good teleſcope, I will deſcribe (by way of introduction to the ſucceeding directions) the ſteps by which I was led to a certain and eaſy method of giving a proper and correct parabolic figure to the metal, even though it came off imperfect from the hones, and an exquiſite poliſh at the ſame time.

Having made many efforts in the former method, which by no means pleaſed me for the reaſons above-mentioned; and having obſerved, from ſome of Mr. SHORT's teleſcopes which fell into my hands, that the high luſtre of the poliſh could never have been produced in the manner above deſcribed, but by ſome ſofter and more tender ſubſtance; and at the ſame time recollecting, that Sir ISAAC NEWTON had given an account in his Optics of his having finiſhed ſome metals, and conſiderably mended the object glaſs of a refractor, by working both upon a tool whoſe ſurface had been covered with common pitch about the thickneſs of a groat; reflecting, I ſay, upon theſe matters (coarſe and uncertain as this method appeared at firſt ſight) I was determined to try whether I could not get rid of my embarraſſment, by a mode of operation ſomewhat ſimilar. Accordingly, ſhortening

DR. SMITH's proceſs, I made a ſet of tools in the manner before deſcribed, except that I was obliged to make ſome ſubſequent alteration in the poliſher which I ſhall preſently deſcribe. Having given a good ſpherical figure to the braſs tool and the bruiſer, and likewiſe to the metal upon the hones, and made the braſs convex tool ſo hot as juſt not to hurt the finger, I tied a lump of common pitch (which ſhould be neither too hard nor too ſoft) in a rag, and holding it in a pair of tongs over a ſtill fire where there was no riſing duſt, till it was ready to ſtrain through the linen, I cauſed it to drop upon the ſeveral parts of the convex tool, till I ſuppoſed it would cover the whole ſurface about double the thickneſs of a ſhilling; then ſpreading the pitch as equally as I could, I ſuffered the poliſher (by which name I ſhall for the future call this tool) to grow quite cold. I then warmed the bruiſer ſo hot as almoſt to burn my fingers, and having fixed it to the bench with its face upwards, I ſuddenly placed the poliſher upon it, and quickly ſlid it off; by this means rendering the ſurface of the pitch more equal. The pitch is then to be wiped off from the bruiſer with a little tow; and by touching the ſurface with a tallow candle, and wiping it a ſecond time, it will be then perfectly clean and fit for a ſecond proceſs of the ſame ſort, which muſt again be performed as quickly as poſſible;

and this is ordinarily ſufficient to give a general figure to the ſurface of the pitch. The bruiſer and poliſher are then ſuffered to grow perfectly cold, when the pitch, conſidering what has been taken off, will be about the thickneſs of a ſhilling.

It is however here neceſſary to obſerve, that the pitch ſhould be neither very hard and reſinous, nor too ſoft; if the former, it will be ſo untractable as not to work kindly; and if too ſoft, it will in working alter its figure faſter than the metal, and too readily fit itſelf to the irregularity of its figure, if it have any. When both tools were perfectly cold, I gave the poliſher a gentle warmth, and then fixed the bruiſer to the block with its face upwards; and (having with a large camel's-hair bruſh ſpread over the face of the poliſher a little water and ſoap, to prevent ſticking) with ſhort, ſtraight, and round ſtrokes I worked it upon the bruiſer, every now and then adding a little more water and ſoap, till the pitch upon the poliſher had a fine ſurface, and the true form of the bruiſer; and this I continued to do till they both grew perfectly cold together: in this manner the poliſher was perfectly formed in about a quarter of an hour. But here a difficulty aroſe: when I begun to poliſh the metal, I found that the edge of the hole in the metal collected the pitch towards the middle of the poliſher; and though in this method of working I could give an exquiſite poliſh, as the putty lodged itſelf in the pitch exceedingly well, yet the figure of the metal was injured in the middle, nor did indeed the work go on with that equability which is the inſeparable attendant on a good figure. In order to obviate this difficulty, I caſt ſome metals with a continued face, the holes not going quite through, within perhaps the thickneſs of a ſix-pence. I finiſhed two or three metals of this ſort, and the work promiſed and went on very well; but when I came to open the holes, which I did with the utmoſt caution, I found the metals ſhort of perfection; which I attributed to an alteration of the figure from the removal of even that ſmall portion of metal after the ſpeculum had been finiſhed. This I do ſuppoſe was in ſome meaſure the reaſon why I once ſpoiled a very diſtinct and perfect two-foot metal, which bore a charge of two hundred times, only by opening the ſharp part of the edge of the hole, becauſe I thought it bounded the field: ſo eſſentially neceſſary is an exquiſite correctneſs of figure in the ſpeculum of a perfect reflector.

This experiment not ſucceeding, inſtead of caſting the metal without a hole, I made one quite through the middle of the poliſher, a little leſs than that in the ſpeculum. This perfectly anſwered the purpoſe; no more inconvenience aroſe from the gathering of the pitch (for it had now no greater tendency to collect at the center than the ſides) and I finiſhed ſeveral metals ſucceſſively, excellent both in point of figure and poliſh; one of thoſe of two inches diameter and 7,5 focal length, bore a charge of ſixty times and upwards, which when mounted in a teleſcope I gave to my brother. This teleſcope underwent Mr. SHORT's examination, who was pleaſed to remark only, that he thought he had made one more diſtinct.

I muſt obſerve, that in this method of working the poliſhing goes on in an agreeable, uniform, and ſmooth manner; and that the ſmall degree of yielding in the pitch (which is actually not more than the wearing of the metal) produces that mutual accommodation of ſurfaces ſo neceſſary to a true figure. In the beginning of the poliſh, and indeed for ſome time during the progreſs of it (always remembering now and then to move the metal round its axis) I worked round and round, not far from and always equally diſtant from the center, except that every time, previous to the ſhifting the metal on its axis, I uſed a croſs ſtroke or two; and when the poliſh was nearly compleated, I moſtly uſed croſs ſtrokes, giving a round ſtroke or two likewiſe every time I turned the metal on its axis. I obſerved in this method of working, that the metal always poliſhed faſteſt in the middle;

inſomuch, that half or two-thirds of it would be completely poliſhed when the circumference of it was ſcarcely touched by the tool. Obſerving this in ſome of the firſt metals, and not conſidering that this way of poliſhing was in fact a ſpecies of grinding, and as perfect as that upon the hones, I went on reluctantly with the work, almoſt deſpairing of being able to produce a good figure. However, I always found myſelf agreeably deceived; for when the poliſh was extended to the edge, or within the tenth of an inch of it, I almoſt conſtantly found the figure good, and the performance of the metal very diſtinct. But this ſame circumſtance of apparent defect in the metals, was in fact that to which their perfection was owing; for they all, contrary to my expectation, turned out parabolic. However I did not for a great while know any certain way of giving that degree of parabolic tendency which was juſt neceſſary, and which will be deſcribed hereafter. It was a long time before I got rid of my prejudice againſt this apparent imperfection in the proceſs, or could reconcile myſelf to the irregular manner in which the poliſh proceeded; for I looked upon it as a certain ſource of error, and notwithſtanding I ſaw it eventually ſucceed, yet whenever I chanced to find that a metal, when firſt applied to the poliſher, took the poliſh equally all over, and conſequently the whole buſineſs did not take up above ten minutes; under thoſe circumſtances, I ſay, I always uſed to pleaſe myſelf with the expectation of a correct figure, at leaſt as much ſo as the metal had received from the hones, where the ſurface was but juſt and equally taken off by the putty; but in this I conſtantly found myſelf deceived, and the metal turned out good for nothing. In ſhort, at this time, though I ſpeculatively knew that a parabolic figure was neceſſary to a perfect image, I yet conſidered it as of little practical conſequence.

From the foregoing experiments, and a number of ſucceeding trials, I at length diſcovered a certain way of giving a correct parabolic figure, and an exquiſite poliſh at the ſame time. This, which I have ſtrong reaſons to believe was Mr. SHORT's method, I will now deſcribe in as few words as I can.

How to poliſh the ſpeculum.

It is firſt neceſſary to obſerve, that, in order to avoid the detrimental intruſions of any particles of emery, it would not be right to poliſh in the ſame room where the metal and tools were ground, nor in the ſame cloaths which were worn in the former proceſs; at leaſt it would be neceſſary to keep the bench quite wet, to prevent any duſt from riſing.

Having then made the poliſher by coating the braſs convex tool equally with pitch, which we ſuppoſe ſmoothed and finiſhed with the braſs tool in the manner before deſcribed, and which is a very eaſy proceſs, the whole operation is begun and finiſhed in the following manner.

The leaden weight or handle upon the back of the metal ſhould be divided into eight parts, by ſo many deep ſtrokes of a graver upon the upper ſurface of the lead, marking each ſtroke with the numbers 1, 2, 3, 4, and ſo on, that the turns of the metal in the hand may be known to be uniform and regular.

To prevent any miſchief from coarſe particles of putty, I always waſh it immediately before uſing. In order to this, put about half an ounce of putty into an ounce phial, and fill it two-thirds with water; then having ſhaken the whole, let the putty ſubſide, and ſtop the bottle with a cork.

In a tea-cup with a little water, there ſhould be a full-ſized camel's-hair bruſh, and a piece of dry clean ſoap in a galley-pot: a ſoft piece of ſpunge will alſo be neceſſary. Theſe, as well as the metal bruiſer and poliſher, ſhould be conſtantly covered from duſt.

The poliſher being fixed down, and the camel's-hair bruſh, being firſt wetted and rubbed a little over the ſoap, let every part of the tool be bruſhed over therewith; then work the bruiſer with ſhort, ſtraight, and round ſtrokes, lightly upon the tool, and continue to do ſo, now and then turning it, till the poliſher have a good face, and be fit for the metal. Then having ſhaken up the putty in the phial, and touched the poliſher in five or ſix places with the cork wetted with that and the water, place the bruiſer upon the tool, and give a few ſtrokes upon the putty to rub down any gritty particles; after which, having removed it, work the metal lightly upon the poliſher round and round, carrying the edges of the ſpeculum, however, not quite half an inch over the edge of the tool, and now and then with a croſs ſtroke.

The firſt putty, and indeed all the ſucceeding applications of it, ſhould be wrought with a conſiderable while; for if time be not given for the putty to bed itſelf in the pitch, and any quantity of it lie looſe upon the poliſher, it will accumulate into knobs, which will injure the figure of the metal: and therefore as often as ever ſuch knobs ariſe, they muſt be carefully ſcraped off with the point of a penknife, and the looſe ſtuff taken away with the bruſh. After the putty is well wrought into the pitch, ſome more may be added in the ſame manner, but never much at a time, and always remembering to work upon it firſt with the bruiſer, for fear any gritty particles may find their way upon the poliſher. If the bruiſer be apt to ſtick, and do not ſlide ſmoothly upon the pitch, the ſurface of either tool may be occaſionally bruſhed over with the ſoap and water, but it muſt be remembered that the wet bruſh muſt be but lightly rubbed upon the ſoap.

In the beginning of this proceſs little effect is produced, and the metal does not ſeem to poliſh faſt, in ſome meaſure owing to its taking the poliſh in the middle, and perhaps becauſe neither that nor the bruiſer move evenly upon the poliſher: but a little perſeverance will bring the whole into a good temper of working; and, when the pitch is well defended by the coating of the putty, the proceſs will advance apace, and the former acquiring poſſibly ſome little warmth, the metal moves more agreeably over it, with an uniform and regular friction. All this while the metal muſt have no more preſſure than that which it derives from its own weight and that of the handle; and the poliſher muſt never be ſuffered to grow dry, but, as often as it has any tendency to do ſo, the edges of it muſt be moiſtened with the hair-pencil; and now and then, even when freſh putty is not laid on, the ſurface of the poliſher ſhould be touched with the bruſh to keep it moiſt.

When the poliſh of the metal nearly reaches the edge (for it always, as I ſaid before, begins in the middle) you muſt alter your method of working; for now the round ſtrokes muſt be gradually altered for the ſhort and ſtraight ones. Suppoſing then you are juſt beginning to alter them; after having put on freſh putty, and gently rubbed it with two or three ſtrokes of the bruiſer, you place the metal on the tool, and after a ſtroke or two round and round, give it a few forward and backward, and from ſide to ſide, but with the edges very little over the tool; then having turned the metal one-eighth round in your hand, and having moved yourſelf as much round the block (which muſt be remembered throughout the whole proceſs) you go on again with a ſtroke or two round, to lead you only to the croſs ſtrokes, which are now to be principally uſed, and with more boldneſs. After this has been done ſome time, the metal will begin to move ſtiffly as the friction now increaſes, and the ſpeculum poliſhes very beautifully and faſt; and the whole ſurface of the poliſhing tool will be equally covered over with a fine metallic bronze. The tool even now muſt not be ſuffered to become dry; a ſingle round ſtroke in each of your ſtations and turnings of the metal will be ſufficient, and the reſt muſt all be croſs ones, for we are completing a circular figure. You muſt now be very diligent, for the poliſher drying, and the friction increaſing very faſt, the buſineſs of the ſpherical figure is nearly at an end. As the metal wears much, its ſurface muſt be now and then cleaned, with a piece of ſhammy leather, from the black ſtuff which collects upon it; and the poliſher likewiſe from the ſame matter, with a ſoft piece of wet ſponge. You will now be able to judge of the perfect ſpherical figure of the metal and tool, when there is a perfect correſpondence between the ſurfaces, by the fine equable feel there is in working, which is totally free from all jerks and inequalities. Having proceeded thus far, you may put the laſt finiſhing to this figure of the metal by bold croſs ſtrokes, only three or four in the directions of each of the eight diameters, turning the metal at the ſame time: this muſt be done quickly, for it ought, in this part of the proceſs particularly, to be remembered, that, if you permit the tool to grow quite dry, you will never be able, with all your force, to ſeparate that and the metal, without deſtroying the poliſher by heat.

The metal has now a beautiful poliſh and a true ſpherical figure, but will by no means make a ſharp diſtinct image in the teleſcope: for the ſpeculum (if it be tried in the manner hereafter recommended) will not be found to make parallel rays converge without great aberration; indeed the deviation will be ſo great, as to be very ſenſibly perceived by a great indiſtinctneſs in the image.

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How to give the parabolic figure to the metal.

In order then to give the ſpeculum the laſt and finiſhing figure, which is done by a few ſtrokes, it muſt be particularly remarked, that by working the metal round and round, the ſphere of the poliſher by this means growing leſs, it wears faſteſt in the middle: and as a ſegment of a ſphere may become parabolic, by opening the extremes gradually from within outwards, ſo it may be equally well done by increaſing the curvature in the middle, in a certain ratio, from without inwards.

Suppoſing then the metal to be now truly ſpherical, ſtop the hole in the poliſher, by forcing a cork into it underneath, about an inch, ſo that it do not reach quite to the ſurface; and having waſhed off any mud that may be on the ſurface of the tool with a wet ſoft piece of ſponge, whilſt the ſurface of it is a little moiſt, place the center of the metal upon the middle of the poliſher; then having, with the wet bruſh, lodged as much water round the edge of the metal as the projecting edge will hold, fill the hole of the metal and its handle with water, to prevent the evaporation of the moiſture, and the conſequent adheſion between the ſpeculum and poliſher, and let the whole reſt in this ſtate two or three hours: this will produce an intimate contact between the two, and by parting with any degree of warmth they may have acquired by the vicinity of the operator, they will grow perfectly cold together.

By this time you may puſh out the cork from the poliſher, to diſcharge the water, and give the metal the parabolic figure in the following manner.

Move the metal gently and ſlowly at firſt, a very little round the centre of the poliſher (indeed after this reſt it will move ſtiffly) then increaſing by degrees the diameter of theſe ſtrokes, and turning the metal frequently round its axis, give it a larger circular motion, and this without any preſſure but its own weight, and holding it looſely between the fingers: this manner of working may ſafely be continued about two minutes, moving yourſelf as uſual round the block, and carrying the round ſtrokes in their increaſed and largeſt ſtate, not more than will move the edge of the metal half an inch or five-eighths over the tool. The ſpeculum muſt not all this while be taken off from the poliſher; and conſequently no freſh putty can be added. It will not be ſafe to continue this motion longer than the time above-mentioned; for if the parabolic tendency be carried the leaſt too far, it will be impoſſible to recover a true figure of that kind but by going through the whole proceſs for the ſpherical one in the manner before deſcribed, by the croſs ſtrokes upon the poliſher, which takes a great deal of time. However, when there is occaſion, it may be done; and I have myſelf ſeveral times recovered the circular figure, when I had inadvertently gone too far with the parabolic; and ultimately finiſhed the metal on the poliſher without the uſe of the hones.

To try the true figure of the metal.

It will now be proper to try the figure of the ſpeculum, and that is always beſt done by placing it in the teleſcope it is intended for. In order to this, I uſe the inſtrument as a kind of microſcope, placing the object, however, at ſuch a diſtance that the rays may be nearly parallel. At about twenty yards a watch-paper, or ſome ſuch object, on which there are ſome very fine hair ſtrokes of a graver, is fixed up. The lead muſt be then taken off from the back of the ſpeculum; which is beſt done by placing the edge of a knife at the junction of the lead and metal, when, by ſtriking the back of it with a ſlight blow, the pitch immediately ſeparates, and the handle drops off; the remaining pitch may be ſcraped off with a knife, taking care that none of the duſt ſtick to the poliſhed face of the metal.

Having placed the ſpeculum in the cell of the tube, and directed the inſtrument to the object; make an annular kind of diaphragm with card-paper, ſo as to cover a circular portion of the middle part of the metal between the hole and the circumference, equal in breadth to about an eighth part of the diameter of the ſpeculum: this paper ring ſhould be fixed in the mouth of the teleſcope, and remain ſo during the whole experiment, for the part of the metal covered by it is ſuppoſed to be perfect, and therefore unemployed.

There muſt likewiſe be two other circular pieces of card-paper cut out, of ſuch ſizes, that one may cover the center of the metal by completely filling the hole in the laſt deſcribed annular piece; and the other, ſuch a round piece as ſhall exactly fit into the tube, and ſo broad as that the inner edge may juſt touch the outward circumference of the middle annular piece. It would be convenient to have theſe two laſt pieces ſo fixed to an axis that they may be put in their places, or removed from thence ſo eaſily as not to diſplace or ſhake the inſtrument. All theſe pieces therefore together will completely ſhut up the mouth of the teleſcope.

Let the round piece which covers the center of the metal, or that which has no hole in it, be removed; and, by a nice adjuſtment of the ſcrew, let the image (which is now formed by the center of the mirror) be made as ſharp and diſtinct as poſſible. This being done, every thing elſe remaining at reſt, replace the central piece, and remove the outſide annular one, by which means the circumference only of the ſpeculum will be expoſed, and the image now formed will be from the rays reflected from the outſide of the metal. If there be no occaſion to move the ſcrew and little metal, and the two images formed by theſe two portions of the metal be perfectly ſharp and equally diſtinct, the ſpeculum is perfect, and of the true parabolic curve; or at leaſt the errors of the great and little ſpeculum, if there be any, are corrected by each other.

If, on the contrary, under the laſt circumſtance, the image from the outſide of the metal ſhould not be diſtinct, and it ſhould become neceſſary, in order to make it ſo, that the little ſpeculum be brought nearer, it is plain that the metal is not yet brought to the parabolic figure; but if, on the other hand, in order to procure diſtinctneſs, you be obliged to move the little ſpeculum farther off, then the figure of the great ſpeculum has been carried beyond the parabolic, and hath aſſumed an hyperbolic form. When the latter is the caſe, the circular figure of the metal muſt be recovered (after having fixed on the handle with ſoft pitch) by bold croſs ſtrokes upon the poliſher, finiſhing it again in the manner above deſcribed. If the ſpeculum be not yet brought to the parabolic form, it muſt cautiouſly have a few more round ſtrokes upon the poliſher; indeed a very few of them in the manner before deſcribed make in effect a greater difference in the ſpeculum than would be at firſt imagined. If a metal of a true ſpherical figure were to be tried in the above mentioned manner in the teleſcope (which I have frequently done) the difference of the foci of the two ſegments of the metal would be ſo conſiderable, as to require two or three turns of the ſcrew to adjuſt them; ſo very great is the aberration of a ſpherical figure of the ſpeculum, and ſo improper to procure that ſharpneſs and preciſion ſo neceſſary to a good reflecting teleſcope.

This is by no means the caſe with the object glaſſes of refractors; for beſides that they are in fact never ſo diſtinct as well-finiſhed reflectors, the apertures of them are ſo exceedingly ſmall, compared to the latter, and the number of degrees employed ſo very ſmall, that the inconvenience of a ſpherical figure is not ſo much perceived. Accordingly we obſerve in the generality of reflectors (whoſe ſpecula, unleſs by accident, are always ſpherical) that the only true rays which form the diſtinct image ariſe from the middle of the metal: and unleſs the defect be remedied by a conſiderable aperture, which deſtroys much light, the falſe reflection from the inſide of the metal produces a greyiſh kind of hazineſs, which is never ſeen in Mr. SHORT's or indeed in any good teleſcopes.

Suppoſing that the two foci of the different parts of the metal perfectly coincide, and that, by the union of them when the apertures are removed, the teleſcope ſhews the objects very ſharp and diſtinct, you are not however even then to conclude that the inſtrument is not capable of farther improvement; for you will perceive a ſenſible difference in the ſharpneſs of the image, under different poſitions of the great ſpeculum with reſpect to the little one, by turning round the great metal in its cell, and oppoſing different parts of it to different parts of the little metal, correcting by this means the error of one by the other. This attempt ſhould be perſevered in for ſome time, turning round the great ſpeculum about one-ſixteenth at a time, and carefully obſerving the moſt diſtinct ſituation each time the eye-piece is ſcrewed on: when, by trying and turning the great metal all round, the diſtincteſt poſition is diſcovered, the upper part of the metal ſhould be marked with a black ſtroke, in order that it may always be lodged in the cell in the ſame poſition. This is the method Mr. SHORT always uſed; and the caution is of ſo much conſequence, that he thought it neceſſary to mention it very particularly in his printed directions for the uſe of the inſtrument.

And farther, Mr. SHORT frequently corrected the errors of the great by the little metal in another way. If the great ſpeculum did not anſwer quite well in the teleſcope, he cured that defect ſometimes by trying the effect of ſeveral metals ſucceſſively, by this means correcting the errors of one by the other; for in ſeveral of his teleſcopes which have paſſed through my hands, when the ſizes and powers have been the ſame, I have found that the great metals, though very diſtinct in their proper teleſcopes, yet have, when taken out and changed from one to the other, ſpoiled both teleſcopes, rendering them exceedingly indiſtinct, which could ariſe from no other circumſtance. For this reaſon I ſuppoſe it was, that he kept, ready finiſhed, a great many large metals of the ſame focal length, ſo that, when he wanted to mount a teleſcope, he might from a great choice, be able to combine thoſe metals which ſuited each other beſt. I am ſtrongly inclined to believe this was the caſe, not only from the above obſervation, but becauſe he ſhewed me himſelf a box of finiſhed metals, in which I am ſure there were a dozen and a half of the ſame focal length.

To return: a little uſe in working will make the whole of the proceſs of grinding and poliſhing very eaſy and certain; for though I have endeavoured to be as particular as I can (I am almoſt afraid too much ſo) it is yet ſcarcely poſſible to ſupply a want of dexterity, ariſing from habit only, by the moſt laboured and minute deſcription. And though the above account may appear irkſome to the reader, as it lies cold before the eye, I am very ſure, whoever attempts to make the inſtrument, will not complain of it as tediouſly particular.

I will, however, farther remark, that when the metal begins to move ſtiffly upon the poliſher, and particularly when the figure is almoſt brought to the parabolic form, it will be neceſſary to fix the elbows againſt the ſides, in order to give momentum and equability to the motion of the hand by that of the whole body.

The ſame poliſher will ſerve for ſeveral metals, if it be ſomewhat warmed when you begin to uſe it.

There is another circumſtance, and a material one too, which muſt not be omitted; it is this. For the very ſame reaſon that the pitch ſhould not be too hard or ſoft, the work will not proceed well in the heat of ſummer, or the cold of winter: in the latter, it may be poſſible to remedy the defect by having the room warmed with a ſtove; and in the ſummer, the other inconvenience may perhaps be avoided by uſing a harder kind of pitch; but I much doubt in either caſe whether the work will go on ſo kindly: I have myſelf always wrought in ſpring and autumn.

The proceſs of poliſhing, and indeed grinding upon the hones, will not go on ſo well if it be not continued uninterruptedly from beginning to end; for if the work of either kind be left but for a quarter of an hour, and you then return to it again, it will be ſome time before the tool and metal can get into a kindly way of working; and till they do, you are hurting what was done before.

I have all along ſuppoſed that the metal we have been working was about four inches diameter: if it be either larger or ſmaller, the ſizes of the hones, bruiſer, and poliſher, muſt be proportionably different. I never find any ill conſequence ariſing from the different expanſion from heat and cold in any of the tools, though they be made of different metals and ſubſtances, unleſs the inconvenience, occaſioned by the interruption before hinted at, be thought to reſult from thence; for the alteration produced in the ſurface of the ſpeculum, both by grinding and poliſhing, is ſo much quicker than any that can be ſuppoſed to ariſe from the former cauſe, that it is never attended with any practical conſequence.

Magnifying very minute objects, and particularly reading at a diſtance, have been generally conſidered as the ſureſt teſts of the goodneſs of a teleſcope; and indeed when the page is placed at a great diſtance, ſo that the letters ſubtend but a very ſmall angle at the eye, if then they appear with great preciſion and ſharpneſs, it is moſt probable that the inſtrument is a good one. But we are, nevertheleſs, ſometimes apt to be deceived by this method; nor is it always poſſible to determine upon the different merits of two inſtruments of equal power, by this mode of examination; for when the letters are removed to the utmoſt extent of the powers of the two inſtruments, the eye is apt to be prejudiced by the imagination. If two or three words can be here and there made out, all the reſt are gueſſed at by the ſenſe; inſomuch that an obſerver, zealous for the honour of his inſtrument, is very apt to deceive himſelf in ſpite of his intentions. The ſurer teſt is by figures, where you can procure no aid from this ſort of deception. In order to examine my reflecting teleſcopes, I made upon a piece of copper and on a black ground, ſix lines conſiſting of about twelve places of gold figures, and each line of figures differing in magnitude, from the ſmalleſt that could be diſtinctly made to thoſe of about two-tenths of an inch long; moreover, the figures in the ſeveral lines were differently diſpoſed, and the ſum of each line alſo differed. It is evident that by this method all gueſs is precluded; and that of two inſtruments, of the ſame powers, that which can make out the leaſt order of figures, which will be known by the ſum, is the beſt teleſcope. Such a plate I cauſed to be fixed up for experiments againſt the top of a ſteeple, about three hundred yards North of my houſe; and it will ſerve to give ſome idea of the diſtinctneſs with which very ſmall figures could be made out at that diſtance, by ſaying, that in a clear ſtate of the air, and with the Sun behind me, with a teleſcope of eighteen inches focal length, which Count BRUHL did me the honour to accept and now has in his poſſeſſion, I have ſeen the legs of a ſmall fly, and the ſhadows of them, with great preciſion and exactneſs.

I cannot conclude without indulging myſelf in an obſervation on the amazing ſagacity of Sir ISAAC NEWTON in every ſubject upon which he thought fit to employ his attention. It was he who firſt propoſed, and indeed practiſed, the poliſhing with pitch; a ſubſtance which at firſt ſight perhaps every one but himſelf would have thought very improper, from its ſoftneſs, to produce that correctneſs of figure ſo neceſſary upon theſe occaſions; and yet I do believe, that it is the only ſubſtance in nature that is perfectly well calculated for the purpoſe; for at the ſame time that it is ſoft enough to ſuffer the putty to lodge very freely on its ſurface, and for that reaſon to give a moſt tender and delicate poliſh; it is likewiſe totally inelaſtic, and therefore never, from that principle, ſuffers any alteration in the figure you give it. If the firſt makers of the inſtrument, therefore, had given proper credit to, or had ſimply followed the hint Sir ISAAC gave, it would have ſaved them infinite trouble, and they would have produced much better inſtruments; but the pretended refinement, of drawing a tincture from pitch with ſpirits of wine, affords you only the reſinous, hard, and untractable part of the pitch, diveſted of all that part of its original ſubſtance which is neceſſary to give it that accommodating pliability in which its excellence conſiſts.

It is needleſs to ſwell this account with a detail of the proceſs for poliſhing the little ſpeculum, as it muſt be conducted in the ſame manner which has been already deſcribed in that of the large one; only obſerving, that as the little metal has an uninterrupted face, without a hole, ſo there is no occaſion for one in the poliſher; and likewiſe that, as a ſpherical figure is all that need here be practically attempted, ſo the difficulty in finiſhing is infinitely ſhort of that of the other.

As it is always neceſſary to ſolder to the back of the little ſpeculum a piece of braſs, as a fixture for the ſcrew to adjuſt its axis, I ſhall juſt hint a ſafe and neat method of doing it, which may be very uſeful to the optical or mathematical inſtrument-maker upon other occaſions. Having cleaned the parts to be ſoldered very well, cut out a piece of tin-foil the exact ſize of them; then dip a feather into a pretty ſtrong ſolution of *ſal ammoniac* in water, and rub it over the ſurfaces to be ſoldered; after which place the tin-foil between them as faſt as you can (for the air will quickly corrode their ſurfaces ſo as to prevent the ſolder taking) and give the whole a gradual and ſufficient heat to melt the tin. If the joints to be ſoldered have been made very flat, they will not be thicker than a hair: though the ſurfaces be ever ſo extenſive, the ſoldering may be conducted in the ſame manner, only that care muſt be taken, by general preſſure, to keep them cloſe together. In this manner, for inſtance, a ſilver graduated plate may be ſoldered on to the braſs limb of a quadrant, ſo as not to be diſcernable by any thing but the different colour of the metals. This method was communicated to me by the late Mr. JACKSON, who during his life kept it a ſecret, as he uſed it in the conſtruction of his quadrants, and is, I believe, not as yet known to any workman.

In the annexed plate are figured the ſhape of the leaden tool for rough-grinding; the hones; and the apparatus to be applied to the mouth of the teleſcope, to aſcertain the true figure of the ſpeculum.

POSTSCRIPT.

It was ſome time after I had written the above account that I ſaw Mr. SHORT's method of poliſhing object glaſſes for refracting teleſcopes, which is publiſhed in the Tranſactions. By that paper I find that what I before ſtrongly ſuſpected is really the caſe, *viz.* that he knew how well pitch was calculated for purpoſes of this kind. Only it may be remarked, that as glaſs is much harder, poliſhes much ſlower, and conſequently does not wear away and alter its figure ſo ſoon as the metal of which the ſpeculum is made; and as at the ſame time (on account of the very ſmall apertures allowed to teleſcopes of this ſort) nothing more than a ſpherical figure is propoſed; he is therefore obliged to uſe pitch in a hard, friable, and ſtubborn ſtate: whereas, conſidering the delicate ſubſtance of the metal ſpeculum, and the figure intended to be given to it, the ſoft pitch of the common ſort, by ſuffering the putty to bed itſelf in its ſubſtance, produces the moſt beautiful poliſh; and by its pliability is better calculated for that mutual accommodation between poliſher and metal, ſo neceſſary to the figure propoſed.

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EXPLANATION OF THE FIGURES.

Fig. 1. The grinder for working off the rough face of the metal; the black ſtrokes repreſent deep grooves made with a graver.

Fig. 2. The bed of hones, which is to complete the ſpherical figure of the ſpeculum, and to render its ſurface fit for the poliſher.

Fig. 3. An apparatus for examining the parabolic figure of the ſpeculum.

AA The mouth of the teleſcope, or edge of the great tube.

BB A thin piece of wood faſtened into, and fluſh with the end of the tube; to which is permanently fixed the annular piece of paſte-board CC, intended to cover, and to prevent the action of the correſponding part of the ſpeculum.

D Another piece of paſte-board, fixed by a pin to the piece of wood BB, on which it turns as on a center; ſo that the great annular opening HH may be ſhut up by the ring FF, or the aperture GG by the imperforate piece E in ſuch manner that, in the firſt inſtance, the reflexion may be from the center, and in the latter from the circumference, of the great ſpeculum.

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Fig. 1.st

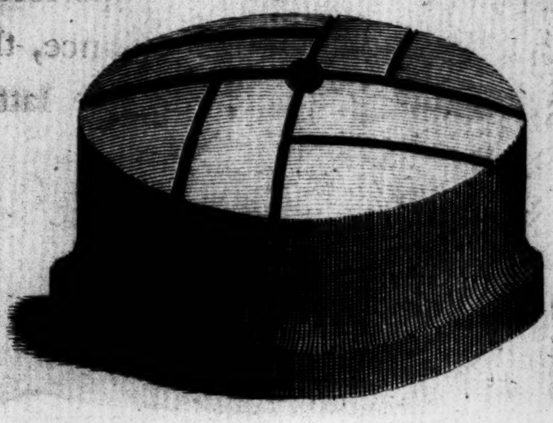


Fig. 2.d

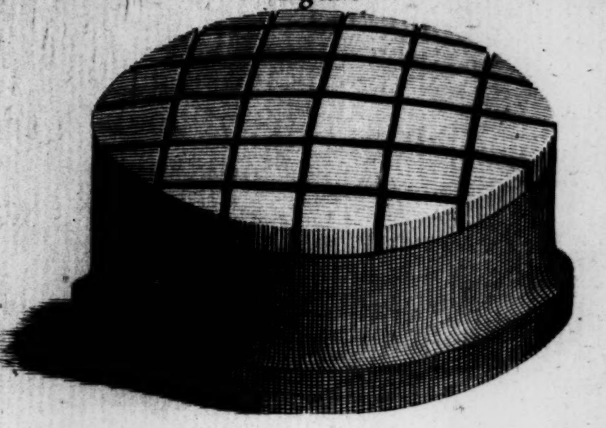
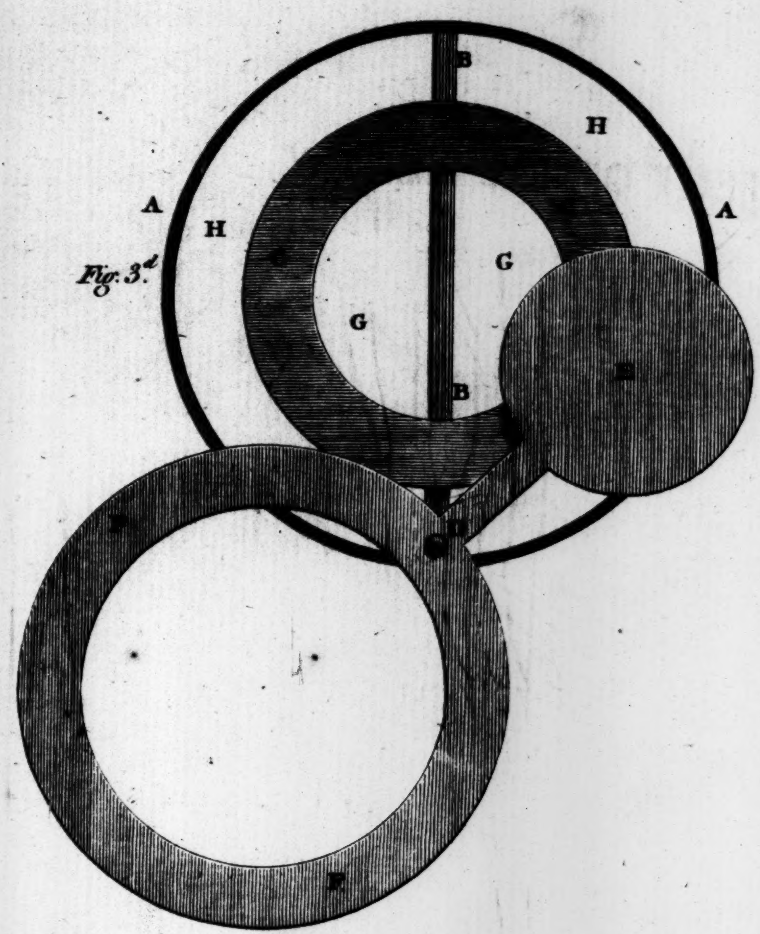


Fig. 3.d



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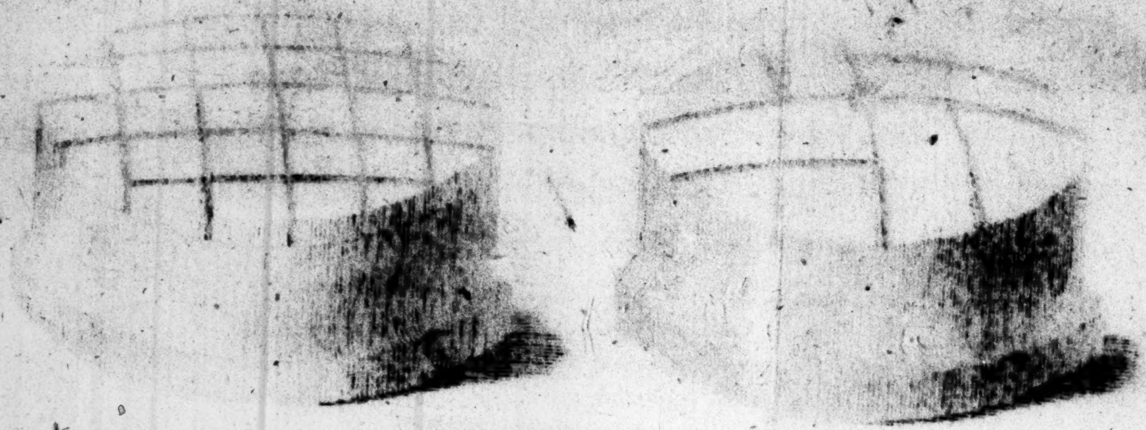

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